

STRENGTHENING NEAR WELL BORE SUBTERRANEAN FORMATIONS

1. Field of the Invention.

[001] The present invention relates to improved methods for completing well bores along producing zones and, more particularly, to methods for strengthening near well bore subterranean formations.

2. Description of the Prior Art.

[002] In many well bores penetrating relatively weak subterranean formations, a casing is cemented in place in the well bore and then perforated to establish communication between the well bore and the subterranean formation. The formation of perforations in the casing generally establishes communication through the casing and surrounding cement into the adjacent subterranean formation. Once such communication established, it is often desirable to fracture the subterranean formation in contact with the perforations to facilitate the flow of desirable hydrocarbons or other fluids present in the formation to the well bore. Various methods and apparatus have been used to effect perforation and fracturing of a subterranean formation. Perforations have been produced mechanically such as by hydrojetting, by jet perforating, and through the use of explosive charges.

[003] Hydrajetting, involves the use of hydraulic jets, *inter alia*, to increase the permeability and production capabilities of a formation. In a common hydrajetting operation, a hydrajetting tool having at least one fluid jet forming nozzle is positioned adjacent to a formation to be fractured, and fluid is then jetted through the nozzle against the formation at a pressure sufficient to form a cavity, known as a "slot." The slot may then be propagated into a further fracture by applying stagnation pressure to the slot. Because the jetted fluids would have to flow out of the slot in a direction generally opposite to the direction of the incoming jetted fluid they are trapped in the slot and create a relatively high stagnation pressure at the tip of a cavity. This high stagnation pressure often causes a microfracture to be formed that extends a short distance into the formation. Pumping a fluid into the well bore to raise the ambient fluid pressure exerted

on the formation may further extend the microfracture while the formation is being hydrajettted. Such a fluid in the well bore will flow into the slot and fracture produced by the fluid jet and, if introduced into the well bore at a sufficient rate and pressure, may be used to extend the microfracture an additional distance from the well bore into the formation.

[004] Fracturing has been accomplished by introducing an aqueous or hydrocarbon liquid into the formation through the perforations at a rate and pressure sufficient to fracture the subterranean formation. In some instances, the fracturing fluid may include a propping agent to prop the created fracture open upon completion of the fracturing treatment. The propped fracture provides an open channel through which fluids may pass from the formation to the well bore.

[005] However, weak subterranean formations, such as coal seams, sandstones, shales and chalk formations, are often too unstable to accept traditional stimulation treatments such a fracturing. Often, the primary point of weakness that makes such treatments unsuccessful is the near well bore area of such a subterranean formation.

SUMMARY OF THE INVENTION

[006] The present invention relates to improved methods for completing well bores along producing zones and, more particularly, to methods for strengthening near well bore subterranean formations.

[007] Some embodiments of the present invention provide a method of strengthening the near well bore region of a subterranean formation comprising the steps of isolating a zone of interest along a well bore; hydrajetting at least one slot in the zone of interest; filling the slot with a consolidation material wherein the viscosity of the consolidation material is sufficient to enable the consolidation material to penetrate a distance into the formation; and, allowing the consolidation material to substantially cure.

[008] Other embodiments of the present invention provide a method of strengthening the near well bore region of a subterranean formation comprising the steps of isolating a zone of interest along a well bore; acidizing the zone of interest with an acid to create a plurality of wormholes; filling the wormholes with a consolidation material wherein the viscosity of the consolidation material is sufficient to enable the consolidation material to penetrate a distance into the formation; and, allowing the consolidation material to substantially cure.

[009] Other and further objects, features and advantages of the present invention will be readily apparent to those skilled in the art upon a reading of the description of preferred embodiments which follows.

DESCRIPTION OF PREFERRED EMBODIMENTS

[010] The present invention relates to improved methods for completing well bores along producing zones and, more particularly, to methods for strengthening near well bore subterranean formations.

[011] Some subterranean formations, such as coal seams, sandstones, shales and chalk formations, are not only too weak to accept stimulation treatments, they also exhibit very low permeabilities, sometimes less than about 5 md. In those formations, the consolidating material may not be able to permeate far enough into the subterranean formation near the well bore to offer a sufficient increase in strength such that the subterranean formation can withstand a stimulation treatment. Thus, in some embodiments of the present invention, the near well bore subterranean formation may be subjected to an extending treatment wherein the formation is treated to increase the distance a later placed material, such as a consolidating material, can penetrate the near well bore subterranean formation.

[012] In some embodiments of the methods of the present invention, a zone of interest along a well bore is isolated and the isolated zone is treated to increase the distance in which a later-placed material can penetrate the near well bore subterranean formation, and then a consolidating material is introduced into the slot. The consolidation material acts, *inter alia*, to increase the strength of the near well bore formation such that a traditional stimulation treatment such as fracturing can be performed. By first treating the zone to increase the distance the consolidating material can penetrate into the near well bore formation, the consolidating material is able to consolidate a deeper annulus into the formation from the walls of the well bore.

[013] In other embodiments of the present invention, the extending treatment may be a hydrajetting procedure. Hydrajetting basically involves the use of a tool such as those described in U.S. Patent Nos. 5,765,642, 5,494,103, and 5,361,856, the relevant portions of which are herein incorporated by reference, to create a path, known as a "slot," into the formation from the well bore. The term "slot" should not be read to imply any particular shape of a path. A slot created by a hydrajetting tool creates a path a later placed consolidation material may take to proceed further into the near well bore subterranean formation than it would have been able to proceed if it were forced to penetrate the formation via permeation alone. In some embodiments of the present invention, the hydrajetting tool is used to create slots substantially uniformly

around the well bore circumference such that when the consolidation fluid is introduced to the near well bore area it is able to substantially uniformly penetrate and consolidate an annulus around the well bore into the formation.

[014] In other embodiments of the present invention, the extending treatment is an acidizing procedure. In an acidizing procedure, the near well bore subterranean formation is treated with an acid to create a plurality of tunnels known as "wormholes." Once a wormhole pattern is established, a later placed material, such as a consolidating resin, may be introduced to the near well bore area. By first establishing the wormhole pattern, the consolidation material is able to penetrate further into the near well bore subterranean formation by filling in and then permeating from the wormholes.

[015] Any acid capable of creating wormholes in the subterranean formation may be suitable for use in the present invention. Nonlimiting examples of suitable such acids include hydrochloric acid, hydrofluoric acid, acetic acid, formic acid, citric acid, ethylene diamine tetra acetic acid ("EDTA"), and combinations thereof. When selecting an acid for use in the present invention, consideration should be given to the formation temperature, the acid-reactivity of the formation, the porosity of the formation, formation permeability, and injection rate. By way of example and not of limitation, in a formation having a relatively high acid-reactivity and a relatively high temperature, more intricate wormholes may be achieved by using a relatively weak acid such as acetic acid. More intricate wormholes may allow for a more uniform distribution of the consolidation material into the subterranean formation, thus better strengthening in the near well bore area. In addition to considering the type of acid used, the concentration of acid must also be considered. Selection of the concentration of acid to be used is related to the same considerations listed above with respect to selection of the type of acid. It is within the ability of one skilled in the art, with the benefit of this disclosure, to consider the formation at issue, the consolidation desired, and the acid chosen to select an appropriate acid concentration.

[016] Wormholes formed via an acidizing extending process are preferably symmetrical. A 1999 Society of Petroleum Engineers Paper (paper number 54719 entitled "Fundamentally New Model of Acid Wormholing in Carbonates," the relevant disclosure of which is herein incorporated by reference) postulates that the formation of wormholes into

carbonaceous material may be highly symmetrical. The paper further notes that wormhole length may be predominately controlled by the matrix porosity of the formation and the volume of acid pumped rather than by the acid's reactivity, as was taught in the prior art. Thus, while the concentration of the chosen acid must be considered, that concentration may not have a substantial effect on wormhole length. Moreover, wormhole diameter may be predominately controlled by the acid-reactivity of the formation, the contact time, the matrix porosity of the formation and the volume of acid pumped. Figure 1 shows a highly idealized visualization of how acid may penetrate into the near well bore area to create a series of intricate and symmetrical wormholes that may act as an extending treatment of the present invention.

[017] In some embodiments of the present invention, the consolidation material is a one-component curable resin that does not require the use of an external catalyst to cure. Suitable such resin consolidation materials include, but are not limited to, two-component epoxy-based resins, furan-based resins, phenolic-based resins, high-temperature (HT) epoxy-based resins, and phenol/phenol formaldehyde/furfuryl alcohol resins.

[018] Selection of a suitable resin consolidation material may be affected by the temperature of the subterranean formation to which the fluid will be introduced. By way of example, for subterranean formations having a bottom hole static temperature ("BHST") ranging from about 60°F to about 250°F, two-component epoxy-based resins comprising a hardenable resin component and a hardening agent component containing specific hardening agents may be preferred. For subterranean formations having a BHST ranging from about 300°F to about 600°F, a furan-based resin may be preferred. For subterranean formations having a BHST ranging from about 200°F to about 400°F, either a phenolic-based resin or a one-component HT epoxy-based resin may be suitable. For subterranean formations having a BHST of at least about 175°F, a phenol/phenol formaldehyde/furfuryl alcohol resin may also be suitable.

[019] One resin consolidation material suitable for use in the methods of the present invention is a two-component epoxy based resin comprising a hardenable resin component and a hardening agent component. The hardenable resin component is comprised of a hardenable resin and an optional solvent. The solvent may be added to the resin to reduce its viscosity for ease of handling, mixing and transferring. It is within the ability of one skilled in the art with the benefit of this disclosure to determine if and how much solvent may be needed to achieve a viscosity

suitable to the subterranean conditions. Factors that may affect this decision include geographic location of the well and the surrounding weather conditions. An alternate way to reduce the viscosity of the liquid hardenable resin is to heat it. This method avoids the use of a solvent altogether, which may be desirable in certain circumstances. The second component is the liquid hardening agent component, which is comprised of a hardening agent, a silane coupling agent, a surfactant, an optional hydrolyzable ester for, *inter alia*, breaking gelled fracturing fluid films on the proppant particles, and an optional liquid carrier fluid for, *inter alia*, reducing the viscosity of the liquid hardening agent component. It is within the ability of one skilled in the art with the benefit of this disclosure to determine if and how much liquid carrier fluid is needed to achieve a viscosity suitable to the subterranean conditions.

[020] Examples of hardenable resins that can be utilized in the liquid hardenable resin component include, but are not limited to, organic resins such as bisphenol A-epichlorohydrin resins, polyepoxide resins, novolak resins, polyester resins, phenol-aldehyde resins, urea-aldehyde resins, furan resins, urethane resins, glycidyl ethers and mixtures thereof. The resin utilized is included in the liquid hardenable resin component in an amount sufficient to consolidate particulates. In some embodiments of the present invention, the resin utilized is included in the liquid hardenable resin component in the range of from about 70% to about 100% by weight of the liquid hardenable resin component.

[021] Any solvent that is compatible with the hardenable resin and achieves the desired viscosity effect is suitable for use in the present invention. Preferred solvents are those having high flash points (most preferably about 125°F) because of, *inter alia*, environmental factors. As described above, use of a solvent in the hardenable resin composition is optional but may be desirable to reduce the viscosity of the hardenable resin component for a variety of reasons including ease of handling, mixing, and transferring. It is within the ability of one skilled in the art with the benefit of this disclosure to determine if and how much solvent is needed to achieve a suitable viscosity. Solvents suitable for use in the present invention include, but are not limited to, butylglycidyl ethers, dipropylene glycol methyl ethers, dipropylene glycol dimethyl ethers, dimethyl formamides, diethyleneglycol methyl ethers, ethyleneglycol butyl ethers, diethyleneglycol butyl ethers, propylene carbonates, methanols, butyl alcohols, d'limonene and fatty acid methyl esters.

[022] Examples of the hardening agents that can be utilized in the liquid hardening agent component of the two-component consolidation fluids of the present invention include, but are not limited to, amines, aromatic amines, polyamines, aliphatic amines, cyclo-aliphatic amines, amides, polyamides, 2-ethyl-4-methyl imidazole and 1,1,3-trichlorotrifluoroacetone. Selection of a preferred hardening agent depends, in part, on the temperature of the formation in which the hardening agent will be used. By way of example and not of limitation, in subterranean formations having a temperature from about 60°F to about 250°F, amines and cyclo-aliphatic amines such as piperidine, triethylamine, N,N-dimethylaminopyridine, benzyldimethylamine, tris(dimethylaminomethyl) phenol, and 2-(N₂N-dimethylaminomethyl)phenol are preferred with N,N-dimethylaminopyridine most preferred. In subterranean formations having higher temperatures, 4,4'-diaminodiphenyl sulfone may be a suitable hardening agent. The hardening agent utilized is included in the liquid hardening agent component in an amount sufficient to consolidate particulates. In some embodiments of the present invention, the hardening agent used is included in the liquid hardenable resin component in the range of from about 40% to about 60% by weight of the liquid hardening agent component.

[023] The silane coupling agent may be used, *inter alia*, to act as a mediator to help bond the resin to the surfaces of formation particulates. Examples of silane coupling agents that can be used in the liquid hardening agent component of the two-component consolidation fluids of the present invention include, but are not limited to, n-2-(aminoethyl)-3-aminopropyltrimethoxysilane, 3-glycidoxypentyltrimethoxysilane, and n-beta-(aminoethyl)-gamma-aminopropyl trimethoxysilane. The silane coupling agent used is included in the liquid hardening agent component in an amount capable of sufficiently bonding the resin to the particulate. In some embodiments of the present invention, the silane coupling agent used is included in the liquid hardenable resin component in the range of from about 0.1% to about 3% by weight of the liquid hardening agent component.

[024] Any surfactant compatible with the liquid hardening agent may be used in the present invention. Such surfactants include, but are not limited to, ethoxylated nonyl phenol phosphate esters, mixtures of one or more cationic surfactants, and one or more non-ionic surfactants and alkyl phosphonate surfactants. The mixtures of one or more cationic and

nonionic surfactants are described in U.S. Patent No. 6,311,733, the relevant disclosure of which is incorporated herein by reference. A C₁₂ – C₂₂ alkyl phosphonate surfactant is preferred. The surfactant or surfactants utilized are included in the liquid hardening agent component in an amount in the range of from about 2% to about 15% by weight of the liquid hardening agent component.

[025] Use of a diluent or liquid carrier fluid in the hardenable resin composition is optional and may be used to reduce the viscosity of the hardenable resin component for ease of handling, mixing and transferring. It is within the ability of one skilled in the art, with the benefit of this disclosure, to determine if and how much liquid carrier fluid is needed to achieve a viscosity suitable to the subterranean conditions. Any suitable carrier fluid that is compatible with the hardenable resin and achieves the desired viscosity effect is suitable for use in the present invention. The liquid carrier fluids that can be used in the liquid hardening agent component of the two-component consolidation fluids of the present invention preferably include those having high flash points (most preferably above about 125°F). Examples of liquid carrier fluids suitable for use in the present invention include, but are not limited to, dipropylene glycol methyl ethers, dipropylene glycol dimethyl ethers, dimethyl formamides, diethyleneglycol methyl ethers, ethyleneglycol butyl ethers, diethyleneglycol butyl ethers, propylene carbonates, d'limonene and fatty acid methyl esters.

[026] Another resin suitable for use in the methods of the present invention is a furan-based resin. Suitable furan-based resins include, but are not limited to, furfuryl alcohol resins, mixtures furfuryl alcohol resins and aldehydes, and a mixture of furan resins and phenolic resins. A furan-based resin may be combined with a solvent to control viscosity if desired. Suitable solvents for use in the furan-based consolidation fluids of the present invention include, but are not limited to 2-butoxy ethanol, butyl acetate, and furfuryl acetate.

[027] Still another resin suitable for use in the methods of the present invention is a phenolic-based resin. Suitable phenolic-based resins include, but are not limited to, terpolymers of phenol, phenolic formaldehyde resins, and a mixture of phenolic and furan resins. A phenolic-based resin may be combined with a solvent to control viscosity if desired. Suitable solvents for use in the phenolic-based consolidation fluids of the present invention include, but are not limited to butyl acetate, butyl lactate, furfuryl acetate, and 2-butoxy ethanol.

[028] Another resin suitable for use in the methods of the present invention is a HT epoxy-based resin. Suitable HT epoxy-based components include, but are not limited to, bisphenol A-epichlorohydrin resins, polyepoxide resins, novolac resins, polyester resins, glycidyl ethers and mixtures thereof. A HT epoxy-based resin may be combined with a solvent to control viscosity if desired. Suitable solvents for use with the HT epoxy-based resins of the present invention are those solvents capable of substantially dissolving the HT epoxy-resin chosen for use in the consolidation fluid. Such solvents include, but are not limited to, dimethyl sulfoxide and dimethyl formamide. A co-solvent such as a dipropylene glycol methyl ether, dipropylene glycol dimethyl ether, dimethyl formamide, diethylene glycol methyl ether, ethylene glycol butyl ether, diethylene glycol butyl ether, propylene carbonate, d'limonene and fatty acid methyl esters, may also be used in combination with the solvent.

[029] Yet another resin consolidation material suitable for use in the methods of the present invention is a phenol/phenol formaldehyde/furfuryl alcohol resin comprising from about 5% to about 30% phenol, from about 40% to about 70% phenol formaldehyde, from about 10 to about 40% furfuryl alcohol, from about 0.1% to about 3% of a silane coupling agent, and from about 1% to about 15% of a surfactant. In the phenol/phenol formaldehyde/furfuryl alcohol resins suitable for use in the methods of the present invention, suitable silane coupling agents include, but are not limited to, N-2-(aminoethyl)-3-aminopropyltrimethoxysilane, 3-glycidoxypropyltrimethoxysilane, and n-beta- (aminoethyl)-gamma-aminopropyl trimethoxysilane. Suitable surfactants include, but are not limited to, an ethoxylated nonyl phenol phosphate ester, mixtures of one or more cationic surfactants, and one or more non-ionic surfactants and an alkyl phosphonate surfactant. Suitable solvents for use in the phenol/phenol formaldehyde/furfuryl alcohol consolidation fluids of the present invention include, but are not limited to 2-butoxy ethanol, butyl acetate, and furfuryl acetate.

[030] Some embodiments of the methods of the present invention provide a method of strengthening the near well bore area of a subterranean formation comprising the steps of isolating a zone of interest along a well bore, hydrjetting at least one slot in the zone of interest, introducing a consolidation material into the well bore and the slot, and allowing the consolidation material to substantially cure.

[031] Some other embodiments of the methods of the present invention provide a method of strengthening the near well bore area of a subterranean formation comprising the steps of isolating a zone of interest along a well bore, acidizing a plurality of wormholes into the formation with an acid, introducing a consolidation material to the wormholes, and allowing the consolidation material to substantially cure.

[032] Once the near well bore area has been treated to increase the distance the consolidating material can penetrate the subterranean formation and the consolidation material has been allowed to penetrate the near well bore subterranean formation and substantially cure, the well bore is essentially sealed from the formation by a layer of cured material. In some embodiments of the present invention, a stimulation treatment, such as fracturing, may then be performed to reconnect the well bore to produceable fluids in the formation.

[033] Therefore, the present invention is well adapted to carry out the objects and attain the ends and advantages mentioned as well as those that are inherent therein. While numerous changes may be made by those skilled in the art, such changes are encompassed within the spirit and scope of this invention as defined by the appended claims.